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MEASUREMENT OF END-EXPIRATORY LUNG VOLUME (FRC) DURING EXERCISE

A. Huch

Translation of: "Messung des end-exspiratorischen Lungenvolumens (FRC) unter den Bedingungen der koerperlichen Arbeit," Zeitschrift fur Praktisch Anaesthesiologie, Volume 8, June 1973, pp. 166-71

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16. Abstract

The author investigates various parameters of respiration in dogs under anesthesia. He then adverts to the possible use of his techniques for measuring lung parameters in working human subjects, since his methodology eliminates any subjective cooperation between researcher and subject.

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MEASUREMENT OF END-EXPIRATORY LUNG VOLUME (FRC) DURING EXERCISE

A. Huch[1]

Beginning with the works of Hall et al. [6], who were the first to use /166* dinitrophenol to investigate circulation and respiration with increased O_2 uptake with an anesthetized dog, alveolo-capillary diffusion, circulation behavior and gas transport with high oxygen consumption were investigated in later works [8, 9, 11]. These works were able to show that even with an increase in oxygen consumption up to 8 times the initial value, both PO_2 and PCO_2 remained essentially constant. It remained to clarify to what extent this visible and impressive adaptation of the alveolar ventilation to metabolism with changes in lung volume, V_L, coincides with the functional residual capacity.

In order to be able to determine these volumes exactly in a dog breathing spontaneously at a high respiration rate, it was necessary to develop a special measuring apparatus described below.

Material, Method, and Methodological Results /167

The tests were begun on 5 dogs with an average weight of 23.0 kg (20 to 27 kg), anesthetized with 80 mg/kg Chloralose and 250 mg/kg Urethan after premedication of 2 mg/kg morphine subcutaneously.

The dogs were placed belly down on a wooden framework from which their legs hung down on each side. Since the temperature rose considerably under the effects of dinitrophenol, the dogs were efficiently cooled by being properly dipped into a tub beneath them filled with water at about 15°C in order to reach a predominantly constant temperature. Breathing tubes were inserted into the trachea and provided with a double valve which has double connections for the inhaling and exhaling breathing tubes.

It can be seen from Figure 1 that a double tube reverse switch is located on this double valve allowing practically unimpeded switching from one open

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[1]Marburg/Lahn University Women's Clinic (Director: Prof. R. Buchholz, M.D.)
*Numbers in the margin indicate pagination in the foreign text.

system to another open system. Here an exhaust system and a spring from an air gun are used to construct the reverse switch. Reversing is controlled in the following way: on the expiratory side of the filling system is found a breath--resistant pipe, used otherwise for pneumotachography, to which a differential statham is connected. Manual maneuvering of the system sketched in Figure 1 records a positive pressure difference caused by the expiration phase in the following respiration cycle, and this is transformed into an electrical impulse. This intensified surge of current triggers an abrupt reversal by means of a magnetic relay.

The narcosis was maintained so steadily that all dogs breathed spontaneously. In the filling stage 11.0% O_2 and 2.0% CO_2 were given in argon. After 10 minutes a switch was made to a mixture of 12.2% O_2 in N_2. In order to avoid any possible atelectasis an overpressure of 30 cm H_2O was blown in during the control period 5 minutes before every measurement.

After the control period the dose of 2:4-dinitrophenol was gradually raised from 10 mg/kg to 15 mg/kg and finally to 20 mg/kg. All measurements were taken during a "steady state" which was generally attained 10 minutes after the dinitrophenol injection.

Air for the analysis of argon in the mass spectrometer (Consolidated Electrodynamics Corporation, Pasadena, type 21-611) was continuously exhausted from the trachea tube, and thus the filling and emptying process was supervised. The volume breathed out, $\dot{V}_E$, was measured spirometrically and adjusted to BTPS, and the respiratory frequency, f_{resp}, was determined either from the spirometer curve or from the continuous argon concentration record of the mass spectrometer. In order to determine the lung volume, V_L, the expired air was collected in an air bag, V_{bag}, until the argon was completely exhausted, mixed manually, measured spirometrically, and the concentration ratio air bag/inspired argon air, $(F_{bag}/F_I)_{AR}$, was determined with the mass spectrometer, while air for the mass spectrometer analysis was continually exhausted. Then the lung volume, V_L, was computed according to the following equation:

$$V_L = V_{bag}\left(\frac{F_{bag}}{F_I}\right)_{Ar}$$

The amount of air exhausted for the determination of the argon concentration was considered. The respiratory pressure fluctuations, ΔP_{resp}, were recorded at the trachea tubes via a statham element and recorded on a scriber. The mean /168 respiratory pressure, P_{TR}, was read from an attenuated water manometer.

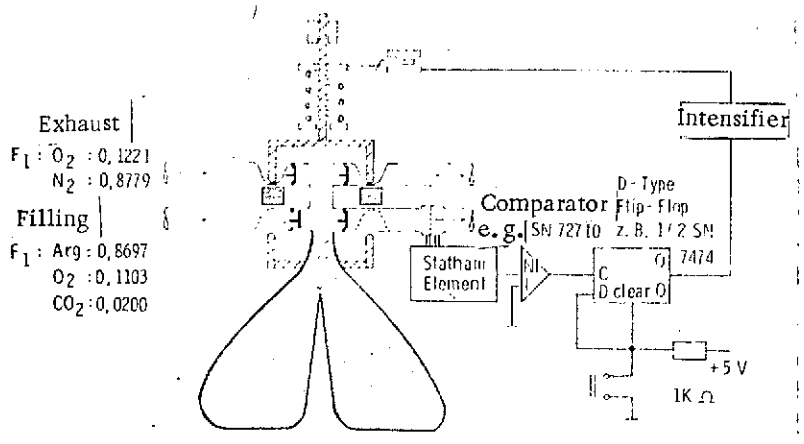

Figure 1. Apparatus for the End Expiratory Switching in the Foreign Gas Collection Method (See Text).

Results

All important results are summarized in Table 1. When dinitrophenol was introduced the respiratory volume, V_T, rose from 428 ml in the control level by a factor of 2.6 to 1,107 ml (Figure 2). At the same time, respiratory frequency, f_{resp}, was changed from 12.6/min by a factor of 3.1 to 38.6/min, corresponding to a ventilation increase from 5.4 ℓ/min to 42.7 ℓ/min. Lung volume, V_L, was changed only to a slight degree (Figure 3). The difference between the control level, V_L = 1,441 ml (BTPS) and the first stage of increasing ventilation with an input of 10 mg/kg dinitrophenol, V_L = 1,387 ml (BTPS), is small. The maximum changes in the following increase levels, corresponding to a DNP enrichment of 15 and 20 mg/kg — exceeded the control value by not more than 10% with 1,558 to 1,594 ml.

The mean lung volume, $V_L + 1/2\ V_T$, increases by 8.23 and 30% at the different increase levels. The proportion of respiratory volume to lung volume, V_T/V_L, increases from 0.30 to 0.69. While the ventilation, $\dot{V}_E$, increases by a factor /169 of 7.9, the maximum pressure fluctuations, Δ, P, increase from 6.8 to 24.0 cm H_2O, and the mean pressure drops from -0.2 to -1.3 cm H_2O.

TABLE 1. LUNG VOLUME WITH INCREASED VENTILATION.

	Control period n = 5	10 mg/kg DNP n = 5	15 mg/kg DNP n = 5	20 mg/kg DNP n = 5
V_T (BTPS) (ml)	428	812 (1,9)	951 (2,2)	1107 (2,6)
f_{resp} (min^{-1})	12,6	31,7 (2,5)	38,9 (3,1)	38,6 (3,1)
$\dot{V}_E$ (l/min)	5,4	25,7 (4,8)	37,0 (6,9)	42,7 (7,9)
ΔP_{resp} (cm H_2O)	6,8	18,3 (2,7)	23,8 (3,5)	24,0 (3,5)
P_{tr} (cm H_2O)	−0,2	−0,8 (4,0)	−1,2 (6,0)	−1,3 (6,5)
V_L (BTPS) (ml)	1441	1387 (0,96)	1558 (1,08)	1594 (1,10)
$V_L + \frac{1}{2} V_T$ (BTPS) (ml)	1655	1793 (1,08)	2034 (1,23)	2148 (1,30)
V_T/V_L	0,30	0,58 (1,9)	0,61 (2,0)	0,69 (2,3)

Numbers in parentheses = increase factors; ΔP_{resp} = maximum pressure changes in trachea; P_{tr} = mean pressure. Commas indicate decimal points.

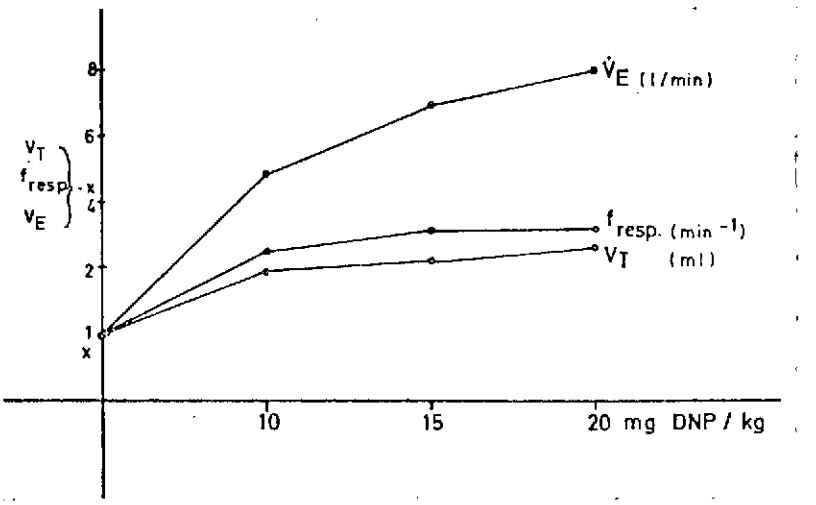

Figure 2. Factors Concerning Increase in Lung Ventilation, $\dot{V}_E$ (l/min), Respiratory Frequency, f_{resp} (min^{-1}), and Respiratory volume V_T, (ml, BTPS). Control period = 1.

Discussion

The measurement of the functional residual capacity, V_L, with an open foreign gas method was described in 1940 by Darling et al. [4], and Cournand et al. [3]. The comparisons of the residual air determination, taken from Gilson et al. [5, 1949], with other methods showed extensive agreement. The foreign gas methods have achieved a solid position in clinical medicine for the measurement of

volume at rest for diagnosing inhomogeneities in lung ventilation [7]. The disadvantage of the method is the fact that the exact measurement of the end--expiratory volume (=FRC) depends on end-expiratory switching by hand, and thus on good cooperation between patient and doctor. In heavy work and correspondingly high respiratory frequencies, and therefore naturally in animal research in particular, only a switch controlled by breathing, and independent of will, can lead to worthwhile results. The method described here also met these conditions at high respiratory frequencies.

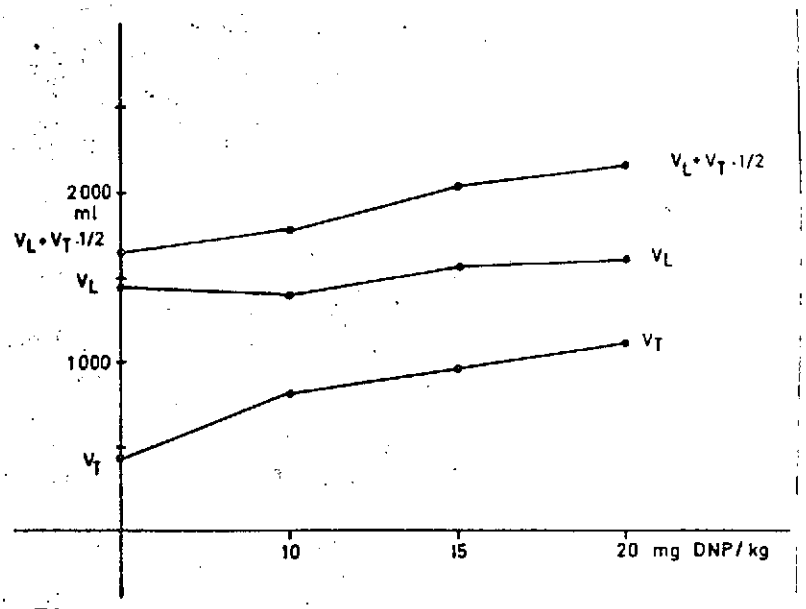

Figure 3. Lung Volume V_L, Respiratory Volume, V_T, Mean Lung Volume $V_L + 1/2\ V_T$, As a Function of 2:4-Dinitrophenol (DNP) Dosage.

In the present series of tests we were able to eliminate measure of the O_2 consumption and determination of other cyclical magnitudes, since a narrow correlation between DNP dosage and oxygen uptake (Figure 4) was demonstrated in a previous series by Huch et al. [8], in addition to other cyclical magnitudes.

In accord with the normal definition in respiratory physiology [12], we include the functional residual capacity in the volume measurement used by us, while the residual volume is provided by the lung volume measured after a maximum expiration. In regard to people Asmussen and Christensen [2] were able to demonstrate that with increasing work the respiratory volume is the result of the expiratory and inspiratory reserve volumes under simultaneous requirements. The

distribution of the increase to the reserve volumes, constant according to these authors, must result in the respiratory midpoint of the thorax remaining unchanged and the mean lung volumes under heavy work corresponding to the rest volume. Motley et al. [10], also found in 34 cases dealing with people that there is practically no change in residual volume during light work. /170

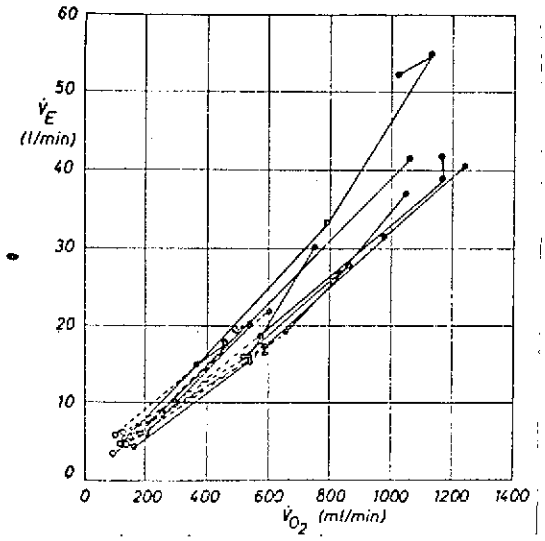

Figure 4. The O_2 Intake as a Function of 2:4-Dinitrophenol Dosage. The values of the individual tests are related to each other. In all tests indicated with solid dots the dogs breathed spontaneously [8].

If the previous results are applied to the present test arrangement to be discussed, it would be expected that the functional residual capacity should drop with increasing respiratory volume by $\Delta V_T/2$, so that a constant respiratory midpoint is guaranteed. However, since the functional residual capacity at all levels remained constant or increased slightly, the present test results indicate a shift of the respiratory midpoint toward the inspirational side, even though not very marked. However, it is also possible to consider the fact that at a constant midpoint with increasing work and increasing ventilation, parts of the lungs which are poorly or not at all ventilated are involved in measurement with the foreign gas method. Thus the increase in $V_L + 1/2\ V_T$ during work would be an expression of the inhomogeneity of lung ventilation at rest. Further tests should clarify the extent to which the respiratory resistances, involving the apparatus used in our tests, have contributed to this apparent or real change in the respiratory midpoint. /171

These tests were carried out in the Physiology Department of the Max-Planck Institute for Experimental Medicine, Goettingen (Professor Doctor J. Piiper).

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